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June 20, 2011

38th EPS conference on plasma physics  
Strasbourg, France  
June 27, 2011 through July 1, 2011

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# Effect of 3-D fields on divertor detachment and associated pedestal profiles in NSTX H-mode plasmas

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## 1. Introduction

The effect of externally applied 3-D magnetic perturbations on the pedestal profiles and the subsequent suppression or triggering of ELMs has been extensively studied in various tokamaks, for example in DIII-D [1] and NSTX [2]. This is a direct consequence of the ‘strike point (SP) splitting’ caused by the 3-D magnetic field perturbations to the plasma edge [3]. As ITER is considering the use of 3-D magnetic fields for the control of ELM transient heat loads, a detailed understanding of the physical mechanism leading to the ELM suppression as well as the changes to the edge transport associated with the application of 3-D fields is necessary. Partial detachment is the divertor operation regime selected for ITER high fusion performance operation, as it allows control of heat fluxes to the divertor and erosion at the material surface during the stationary phase to values acceptable for the PFC operation lifetime. It is therefore essential that the two schemes are compatible with each other. Thus we have investigated the effect of applied 3-D fields on the divertor detachment and its relation to the pedestal profiles in National Spherical Torus Experiment (NSTX).

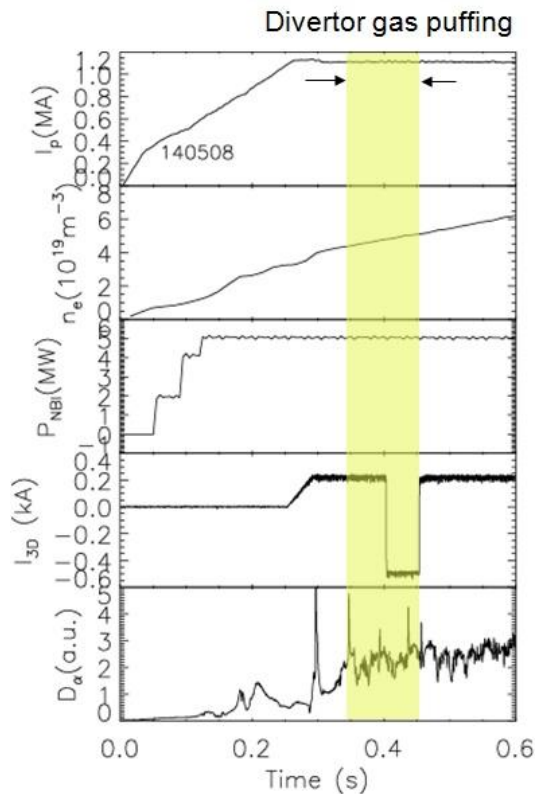


Fig. 1 Time trace of several discharge parameters. Divertor gas injection ( $D_2$ ) was made for  $t=350-450$ ms period (shaded area) and the 3-D fields ( $n=3$ ) were applied for 50ms from  $t=400$ ms

## 2. Experimental setup and measurement technique

Six midplane coils located close to the outer vacuum vessel are used to apply magnetic perturbations in NSTX. The divertor gas injection system was used to induce divertor detachment. The amount of puffed gas was varied to change the divertor plasma condition through high recycling and partial detachment. Heat flux measurements at the lower divertor target are made with a high speed (1.6kHz) dual-band infrared (IR) camera [4,5], installed at toroidal angle  $\phi=135^\circ$ , with  $\sim 50^\circ$  of field-of-view (FOV) at  $r=60\text{cm}$  giving the spatial resolution of 5-7mm. A 2-D heat conduction code, THEODOR [6], is used to calculate the divertor heat flux profile from the measured surface temperature.  $D_\alpha$  emission at the lower divertor target is recorded by a 1-D CCD camera [7] installed at  $\phi=255^\circ$ . It is operated at a 2kHz rate and with sub-mm spatial resolution. Note that we are using the  $D_\alpha$  emission as a proxy for the particle flux in attached plasmas. Two poloidal arrays of ultrasoft x-ray (USXR)

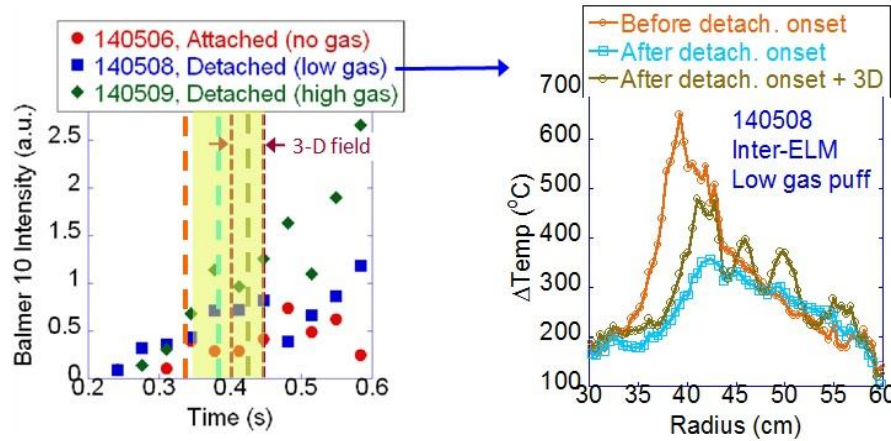


Fig. 2 Time trace of Balmer 10 line intensities (left) and the measured divertor surface temperature profiles by the IR camera (right) for three gas injection cases. Gas puffing was for  $t=350\text{-}450\text{ms}$  (yellow shaded).

diagnostic [8] (16 channels each) recorded line of sight integrated X-ray emissions ( $dI = \epsilon dl$ ) with spectral region 10-100 Å, covering from the plasma edge to the core region. A flush mounted Langmuir probe (LP) with sweeping frequency of 100Hz was also used to monitor divertor plasma conditions such as particle flux ( $I_{sat}^+$ ), electron temperature ( $T_e$ ) and density ( $n_e$ ), and floating potential ( $V_f$ ) [9]. Figure 1 shows the time trace of several discharge parameters.

## 3. Data analysis and interpretation

Divertor plasma detachment is generally signified by a substantial reduction of measured particle flux to the divertor surface and is also accompanied by heat flux reduction. The dual-band IR data shows that the peak in the heat flux profile disappears during the divertor gas injection, making the heat flux profile more flattened. This is a typical signature

of partial detachment, *i.e.* detachment only near the strike point, and LP data also showed that the measured particle flux decreased during the gas puffing period. The measured Balmer 10 line intensities at the divertor surface in figure 2 become stronger for higher gas puffing rate and this indicates higher degree of detachment. For lower gas puffing case, the flattened surface temperature profile by detachment becomes peaked again when the 3-D fields ( $n=3$ ) were applied, which indicates that the divertor plasma reattached. However, divertor plasma

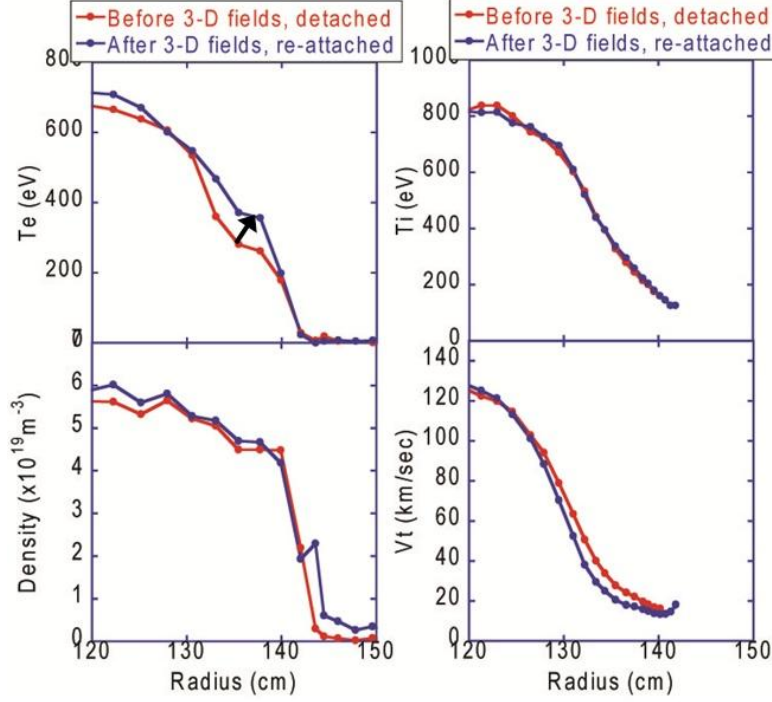


Fig. 3 Temporal evolution of  $T_e$ ,  $n_e$ ,  $T_i$ , and  $v_t$  profiles before (red) and after (blue) the 3-D fields application with the divertor detachment of lower gas puff.

during the 3-D field application period at low puff rates, while the pedestal density increase is more moderate. Thus the pedestal pressure increases, which is consistent with the observed increase of the plasma stored energy. It is interesting to note that  $T_i$  profile showed no change and the  $v_t$  profile continued to decrease during the plasma re-attachment (see figure 3). For the higher gas puff case, the 3-D fields had no impact and the pedestal profiles remained decreased, which is consistent with the continued divertor detachment during the 3-D fields application phase. Figure 4 shows the temporal evolution of the line integrated USXR signals for the cases with and without detachment and the 3-D field application. Channel #0 represents the outer most edge channel and #15 is for the most core channel. It is seen that a steep gradient for the USXR signal exists in the edge region if there is no divertor gas puff. This gradient disappears as the detachment sets on and the temporal evolution of the channel signals indicates that the flattening propagates from the edge toward the core region (top right plot in figure 4). Curiously, for the re-attachment case with the lower gas puff, the applied 3-

with higher gas puff rates remained detached even with the 3-D field application.

We investigated the effect of divertor detachment and the applied 3-D fields on the mid-plane  $T_e$ ,  $n_e$ ,  $T_i$ , and the toroidal rotation velocity ( $v_t$ ) profiles. It is found that detachment reduces pedestal  $T_e$  most clearly, while  $n_e$  reduction was less significant, and the pedestal  $T_i$  and  $v_t$  also decreased. This drop becomes stronger with increasing gas puff rate. During the re-attachment with the lower gas puff rate, the pedestal  $T_e$  profile shows a clear increase

D field restored the edge gradient and again the change propagated from the edge toward the core (bottom left). It may be possible that this restoration is related to the observed pedestal  $T_e$  increase (see figure 3). The edge gradient remained decreased with high gas puff rate (bottom right) and it is consistent with the observation that the divertor plasma remained detached as described above. It is not clear if the 3-D field alone affected the edge USXR channels (top left plot) and changed the gradient or not. In conclusion, the fact that higher gas puff rate prevented the detached plasma from reattaching with applied 3-D fields indicates that the 3-D field application and the divertor detachment can be compatible with each other.

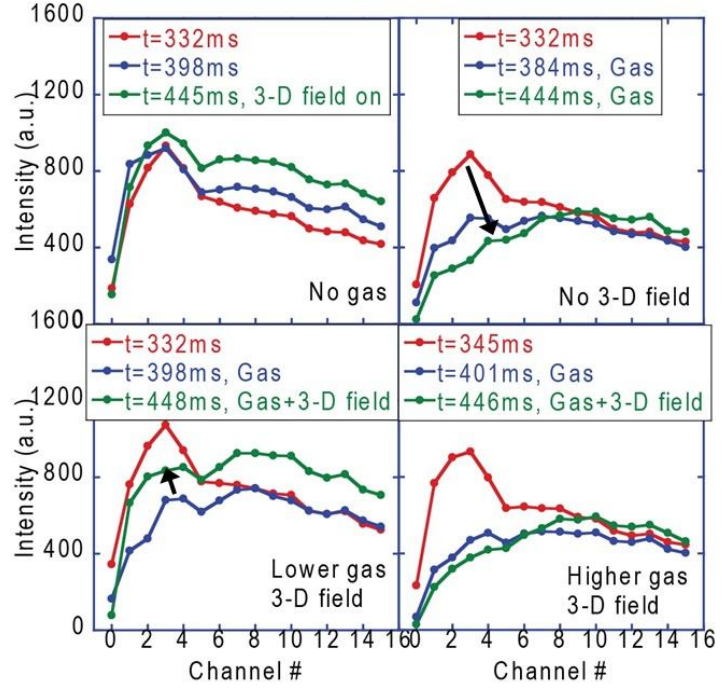


Fig. 4 Line integrated USXR channel signals with and without divertor gas puff and 3-D field application.

## Acknowledgements

This work was funded by the US Department of Energy, contract numbers DE-AC05-000R22725, DE-AC02-09CH11466, DE-AC52-07NA27344(LLNL), and [JHU contract #](#).

We thank A. Herrmann for use of the THEODOR heat conduction code.

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